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Integrated interpretation of helicopter and ground-based geophysical data recorded within the Okavango Delta, Botswana

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ABSTRACT

Integration of information from the following sources has been used to produce a much better constrained and more complete four-unit geological/hydrological model of the Okavango Delta than previously available: (i) a 3D resistivity model determined from helicopter time-domain electromagnetic (HTEM) data recorded across most of the delta, (ii) 2D models and images derived from ground-based electrical resistance tomographic, transient electromagnetic, and high resolution seismic reflection/refraction tomographic data acquired at four selected sites in western and north-central regions of the delta, and (iii) geological details extracted from boreholes in northeastern and southeastern parts of the delta. The upper heterogeneous unit is the modern delta, which comprises extensive dry and freshwater-saturated sand and lesser amounts of clay and salt. It is characterized by moderate to high electrical resistivities and very low to low P-wave velocities. Except for images of several buried abandoned river channels, it is non-reflective. The laterally extensive underlying unit of low resistivities, low P-wave velocity, and subhorizontal reflectors very likely contains saline-water-saturated sands and clays deposited in the huge Paleo Lake Makgadikgadi (PLM), which once covered a 90,000 km^2 area that encompassed the delta, Lake Ngami, the Mababe Depression, and the Makgadikgadi Basin. Examples of PLM sediments are intersected in many boreholes. Low permeability clay within the PLM unit seems to be a barrier to the downward flow of the saline water. Below the PLM unit, freshwater-saturated sand of the Paleo Okavango Megafan (POM) unit is distinguished by moderate to high resistivities, low P-wave velocity, and numerous subhorizontal reflectors. The POM unit is interpreted to be the remnants of a megafan based on the arcuate nature of its front and the semi-conical shape of its upper surface in the HTEM resistivity model. Moderate to high resistivity subhorizontal layers are consistent with this interpretation. The deepest unit is the basement with very high resistivity, high P-wave velocity, and low or complex reflectivity. The interface between the POM unit and basement is a prominent seismic reflector.

1. Introduction

The Okavango Delta is a largely pristine wilderness wetland near the terminus of one of Africa's longest undammed river systems (Fig. 1a). It is an important habitat for numerous plant and animal species in the middle of the otherwise harsh environment of the semi-arid Kalahari Desert. Though commonly referred to as an inland delta, most of it is an alluvial megafan (Fig. 2a; Stanistreet and McCarthy, 1993; Burke and Gunnell, 2008; McCarthy, 2013). In the following, we refer to deltas at the edges of lakes as well as water-covered megafans that have not always terminated at lakes (i.e., the current Okavango Delta) as deltas.

To investigate the poorly known geology and hydrogeology of the Okavango Delta, the government of Botswana commissioned three helicopter transient electromagnetic (HTEM) surveys: a regional survey of the delta (panhandle and megafan in Fig. 2a) and high resolution surveys of two targeted regions of the delta. To allow the data to be meaningfully inverted, it was necessary to pass them through a novel editing, calibration, and processing scheme. Details on this scheme and the initial results of inverting one of the processed high resolution HTEM data sets were presented by Podgorski et al. (2013a), and a highly simplified resistivity model obtained from inverting the processed regional

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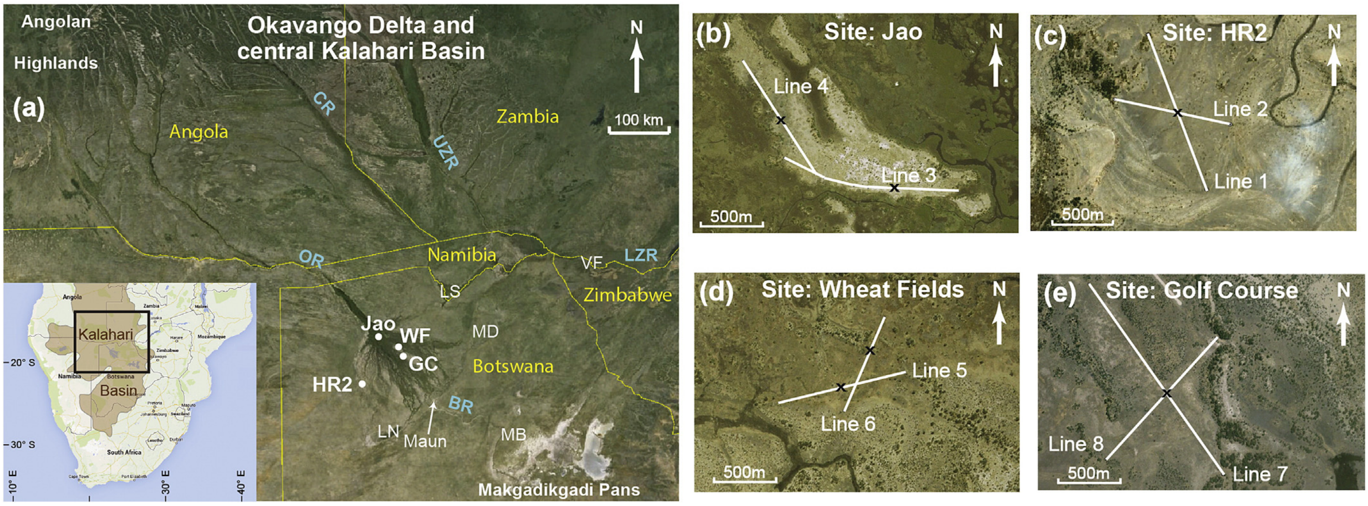

Fig. 1. (a) Okavango Delta in northern Botswana and locations of the four ground-based geophysical study sites: HR2, Jao, WF (Wheat Fields), and GC (Golf Course). BR — Boteti River; CR — Cuando River; LN — Lake Ngami; LS — Linyanti Swamps; LZR — Lower Zambezi River; MB — Makgadikgadi Basin; MD — Mababe Depression; OR — Okavango River; UZR — Upper Zambezi River; VF — Victoria Falls. Inset shows a large part of the Kalahari Basin (after Thomas and Shaw, 1991) and location of main map within southern Africa. ERT, TEM, and seismic reflection/refraction tomographic survey lines at (b) Jao in the upper-central megafan, (c) HR2 in the western megafan, and (d) and (e) Wheat Fields and Golf Course on Chief's Island. Black x's indicate centre points of ERT surveys and the coordinate origin of all ground-based surveys.
Satellite images from Google Earth (©2013 Google).

HTEM data set was first described in a short article by Podgorski et al. (2013b).

The regional HTEM resistivity model contained four distinct layers (i.e., three layers and a half-space) or units. Podgorski et al. (2013b) interpreted the upper unit in terms of sediments deposited in the modern Okavango Delta and speculated that the two successively deeper units represented sediments deposited in a huge paleo lake (Paleo Lake Makgadikgadi — PLM) and a paleo megafan/large inland delta (Paleo Okavango Megafan — POM), respectively. The deepest unit (i.e., half space) was interpreted as basement.

To improve our knowledge of these units, we acquired ground-based electrical resistance tomographic (ERT), transient electromagnetic (TEM), and high resolution seismic reflection/refraction tomographic data at four sites (Fig. 1) carefully chosen to help constrain the interpretation of the HTEM model. Resistivity models derived from the ERT and TEM data recorded at the HR2 and Jao sites have been presented by Meier et al. (2014), and P-wave velocity models and seismic reflection images derived from the seismic data collected at the same two sites have been presented by Reiser et al. (2014). Preliminary versions of these models and images helped guide Podgorski et al.'s (2013b) tentative interpretation.

Since Podgorski et al. (2013a,b), Meier et al. (2014), and Reiser et al. (2014) were submitted for publication, we have inverted the ERT, TEM and seismic refraction data recorded at all four sites using common regularization parameters for each type of data. The uniform regularization used in the inversions of the ERT and the uniform regularization used in the inversions of the TEM data were chosen to produce "optimum" results at the four sites. As a result, the regularization parameters used for our inversions of the ERT and TEM data at HR2 and Jao (Fig. 1) were slightly different from those used by Meier et al. (2014). However,

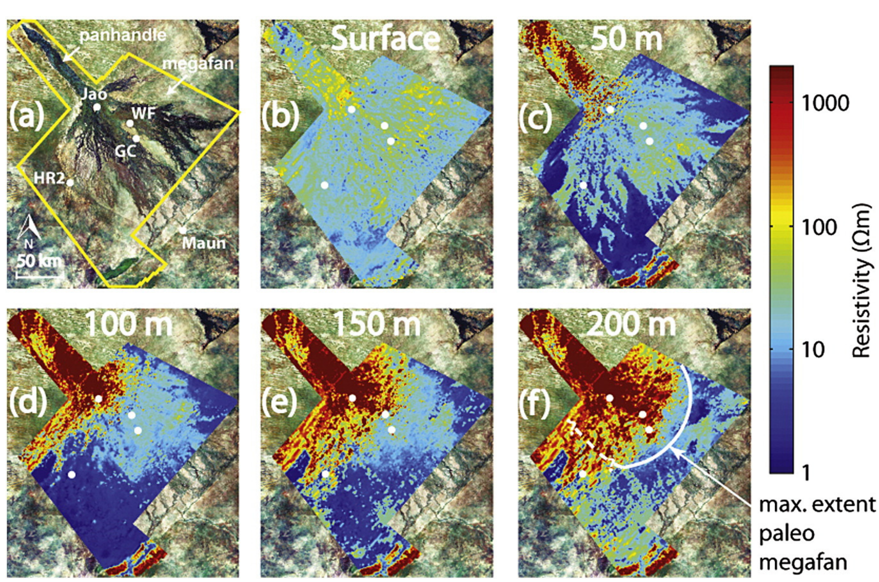

Fig. 2. (a) Outline of HTEM survey area with dots showing locations of the four ground-based geophysical study sites. The HTEM survey was flown with 2-km-line spacing in a SW-NE direction. (b)–(f) Resistivity depth slices extracted from the final model of the regional HTEM data. The proposed paleo megafan is discussed in the text.